PERFORMANCE ANALYSIS ON PERCENTAGE OF WHEEL SLIP FOR A PASSENGER CAR USING GPS AND WHEEL SPEED SENSOR

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SUPERVISOR'S DECLARATION

We hereby declare that we have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Automotive Engineering.

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I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

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ABSTRACT

This thesis deals with the analysis on percentage of wheel slip for a passenger car using GPS and wheel speed sensor. The objective of this thesis is to analyze the percentage of wheel slip for a passenger car in a various velocity, road condition and driving mode. The thesis describes the post-processing method to analyze the percentage of wheel slip and identify the effective rolling radius and the longitudinal tire stiffness for maximum tire life and performance. Driving and braking behaviour of vehicle were both studied in this thesis for paved and unpaved sandy road condition which commonly the contributing factors to the wheel slip to occur. The data used for the analysis is obtained through experimental test using UMP Test Car which has been installed with Wheel Pulse Transducer, Global Positioning System and DEWESOFT software for data acquisition purpose. The post-processing method was performed using Flexpro and Microsoft Office Excel. The post-processing method to analyze the percentage of wheel slip was performed using the SAE definition of wheel slip and the percent error in the distance travel by the car between free rolling and actual condition. Finally, the longitudinal force, the effective rolling radius and the longitudinal tire stiffness was determined for both driving and braking maneuver of vehicle on paved and unpaved sandy road condition. From the results, it is observed that the percentage of wheel slip during driving maneuver is higher for unpaved sandy road condition compares to that the paved road. It is also observed that the longitudinal force of the tire is lower for unpaved sandy road compare to the paved road condition. The effective rolling radius of the tire during driving maneuver was determined to be lower compare to the free rolling radius of the tire. During braking manuever, the results show that the percentage of wheel slip is higher for unpaved sandy road compare to that for paved road condition. The longitudinal force and tire stiffness also observed lower for unpaved sandy road condition. The effective rolling radius of the tire during braking determined higher compared to that in the free rolling radius. The results concluded that the percentage of wheel slip is strongly dependent to the longitudinal force and the tire road friction. Therefore, effective rolling radius and longitudinal tire stiffness obtained can significantly use to improve tire design and construction. The results also can be use to improve the energy usage efficiency and fuel consumption of vehicle.

ABSTRAK

Tesis ini berkaitan dengan analisis peratusan slip roda untuk kereta penumpang menggunakan GPS dan sensor kelajuan roda. Tujuan tesis ini adalah untuk menganalisis peratusan slip roda untuk kereta penumpang dalam pelbagai kelajuan, keadaan jalan dan mod memandu. Tesis ini menjelaskan kaedah pemprosesan pasca untuk menganalisis peratusan slip roda dan mengenalpasti jejari putaran berkesan dan kekerasan tayar membujur untuk maksimum hidup dan prestasi tayar. Perilaku memandu dan pengereman kenderaan dipelajari dalam tesis ini untuk kondisi jalan berturap dan tidak berturap berpasir yang umumnya faktor yang menyumbang kepada slip roda terjadi. Data yang digunakan untuk analisis diperolehi melalui eksperimen menggunakan Kereta Ujian UMP yang telah dipasang dengan Transduser Nadi Roda, System Kedudukan Global dan perisian DEWESOFT untuk tujuan pengambilalihan data. Kaedah pemprosesan pasca dilakukan menggunakan Flexpro dan Microsoft Office Excel. Kaedah pemprosesan pasca untuk menganalisis peratusan slip roda dilakukan dengan menggunakan definisi SAE slip roda dan peratus kesalahan terhadap jarak yang di lalui oleh kereta dengan keadaan putaran sebenar. Akhirnya, daya membujur, jejari putaran berkesan dan kekerasan tayar membujur ditentukan baik untuk memandu dan pengereman manuver kenderaan dalam keadaan jalan berturap dan tidak berturap berpasir. Dari hasil kajian, diperhatikan bahawa peratusan slip roda selama memandu manuver lebih tinggi untuk kondisi jalan berturap berpasir berbanding dengan jalan berturap. Hal ini juga mengamati bahawa daya membujur tayar lebih rendah untuk jalan berturap berpasir berbanding dengan keadaan jalan berturap. Jejari putaran berkesan selama manuver memandu di kira lebih rendah berbanding dengan jejari putaran sebenar tayar. Selama manuver pengereman, keputusan menunjukkan bahawa peratusan slip roda yang lebih tinggi untuk jalan tidak berturap berpasir berbanding dengan kondisi jalan berturap. Watak longitudinal dan simpulan ban juga mengamati lebih rendah untuk kondisi jalan berturap berpasir. Jejari putaran berkesan tayar semasa pengereman ditentukan lebih tinggi berbanding dengan jejari putaran sebenar tayar. Keputusan menyimpulkan bahawa peratusan slip roda sangat bergantung dengan daya membujur dan geseran antara jalan dengan tayar. Dengan itu, jejari putaran berkesan dan kekerasan tayar membujur yang diperolehi secara signifikannya dapat digunakan untuk memperbaiki pembinaan dan rekabentuk tayar. Keputusan ini juga boleh digunakan untuk meningkatkan kecekapan penggunaan tenaga dan penggunaan bahan bakar kenderaan.

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LIST OF SYMBOLS

a_x	Longitudinal acceleration
Cx	Longitudinal tire stiffness
D	Rim diameter
dA	Actual distance that the tire travel
dF	Ideal distance that the tire would freely travel with no slip
$dGPS$	Distance travel measured by GPS
$dWPT$	Distance travel calculated from WPT
F_D	Driving force
Fd	Drag force
F_I	Retarding inertia force
F_R	Reaction force
Frr	Force due to rolling resistance
Fx	Longitudinal force
Fxf	Longitudinal force of front tire
Fxr	Longitudinal force of rear tire
Fz	Normal force
g	Gravitational force
H	Tire height
H/W	Height-to-weight ratio of tire
M	Vehicle mass
N	Number of wheel revolution
R	Free rolling radius of tire
Re	Effective radius of tire

s	Slip
t	Time
T_B	Braking torque
T_D	Driving torque
Vx	Forward velocity
W	Tire width
θ	Grade angle
μ_{bp}	Peak coefficient of friction for braking
μ_{bs}	Sliding coefficient of friction for braking
μ_{dp}	Peak coefficient of friction for driving
μ_{ds}	Sliding coefficient of friction for driving
μ_p	Peak coefficient of friction
μ_s	Sliding coefficient of friction
$\mu_x(s)$	Longitudinal friction coefficient as a function of slip
ω	Wheel angular velocity
ω_e	Effective wheel angular velocity

LIST OF ABBREVIATIONS

ABS	Antilock Braking System
GPS	Global Positioning System
IEEE	Institute of Electrical and Electronics Engineers
LLC	Limited Liability Company
SAE	Society of Automotive Engineers
UK	United Kingdom
UMP	Universiti Malaysia Pahang
USA	United States of America
WPT	Wheel Pulse Transducer

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

In studies of vehicle traction the gross vehicle dynamics and tire/wheel dynamics can be captured by lumped mass models. Simplified models that are often considered for longitudinal braking and acceleration include the single-wheel model and a two-dimensional, two-wheel model (front and rear) or full four-wheel models for cornering (Gillespie, 1992), (Wong, 1978). The dynamics of these systems involve interactions between the vehicle, the tire/wheel assemblies, and the road surface. The force that ultimately slows or accelerates the vehicle is the longitudinal friction force between the road and tire, which can be empirically described in terms of a slip condition at the interface. Thus, writing the equations of motion for any rubber-tire vehicle system requires a description of the friction force generated at the tire/road interface, in addition to the usual laws of motion.

Experimental evidence shows that the longitudinal friction force is proportional to the normal force at the contact (Gillespie, 1992), (Wong, 1978), with a coefficient of friction serving as the constant of proportionality. This coefficient can be conveniently modeled in an empirical manner that depends on the slip (Bakker et al., 1987), (Bakker et al., 1989), which is a dimensionless measure of the difference between the vehicle speed and the circumferential speed of the tire relative to the wheel center. During braking (resp. acceleration), this difference is generated by a brake (resp. engine) torque on the wheel, which acts against (resp. with) the inertia of the vehicle. The slip depends on the dynamics of the vehicle and the tire/wheel, and it also influences their dynamics through the friction force. This feedback results in a system of coupled equations of motion for the vehicle and the tire/wheel. These equations of motion are most often formulated in terms of the vehicle's speed relative to ground and the absolute rotational rate of the tire/wheel. This is a very natural formulation, wherein the slip is merely an internal variable defined in terms of the system's dynamic states, which is used to compute the friction force that appears in the equations of motion.

1.2 PROBLEM STATEMENT

Dynamics and performance of vehicles are result from vehicle operational properties including energy/fuel efficiency, cross-country mobility, tractive and velocity properties, vehicle turnability, and stability of motion and handling. No doubt, the fact that these vehicle operational properties can be considered depends on total power applied to all of the vehicle drive wheels. At the same time, the vehicle operational properties are strongly depending on the total power distribution among the drive wheels. For a given road or off-road conditions, the same vehicle with a constant total power at each drive wheels, but have different power distributions among the drive axles. Left and right wheels of each axle will perform differently; this is how the criteria of the above-listed operational properties will have different quantities (Vantsevich, 2007).

There might be one problem that will occur during driving or braking of vehicle that is wheel slip. While the vehicle wheels are spinning, the driving force on the tires will reduces considerably and the vehicle cannot speed up as desired. This might even become very difficult to control the vehicle under these conditions (Haskara et al., 2000). Wheel slip is one of the contributing factors that the energy losses of the engine to occur. Torque produce is wasted because of that the tire did not have interface contact with the road and the car didn't move with these power produced.

Due to the power losses, the wasted torque produce and the important of the wheel slip parameter in vehicle control system; it is important to study the relation between the longitudinal force and the percentages of the wheel slip so that we can calculate the effective radius of the tires and estimate the longitudinal tire stiffness for a maximum tire life and performance.

1.3 PROJECT OBJECTIVES

(i) To collect the experimental data using Global Positioning System (GPS) and high-resolution Wheel Pulse Sensors.

(ii) To analyze the percentage of wheel slip for a passenger car in a various velocity, road condition and driving mode.

1.4 PROJECT SCOPES

(i) Literature review on the tractive properties of tire, traction limited acceleration and Antilock Braking System.

(ii) Test car system installation and experiment procedures preparation for acceleration and braking test.

(iii) Analysis on percentage of wheel slip for driving and braking maneuver.

(iv) Conclude the project with details discussion on the result in a final report.

1.5 HYPOTHESIS

In preliminary testing, increased inflation pressure appeared to systematically lower the longitudinal stiffness. The data gathered must be consistent with the assumption of a linear relationship between force and slip at low levels of slip as predicted by classical tire models.

1.6 PROJECT FLOW CHART

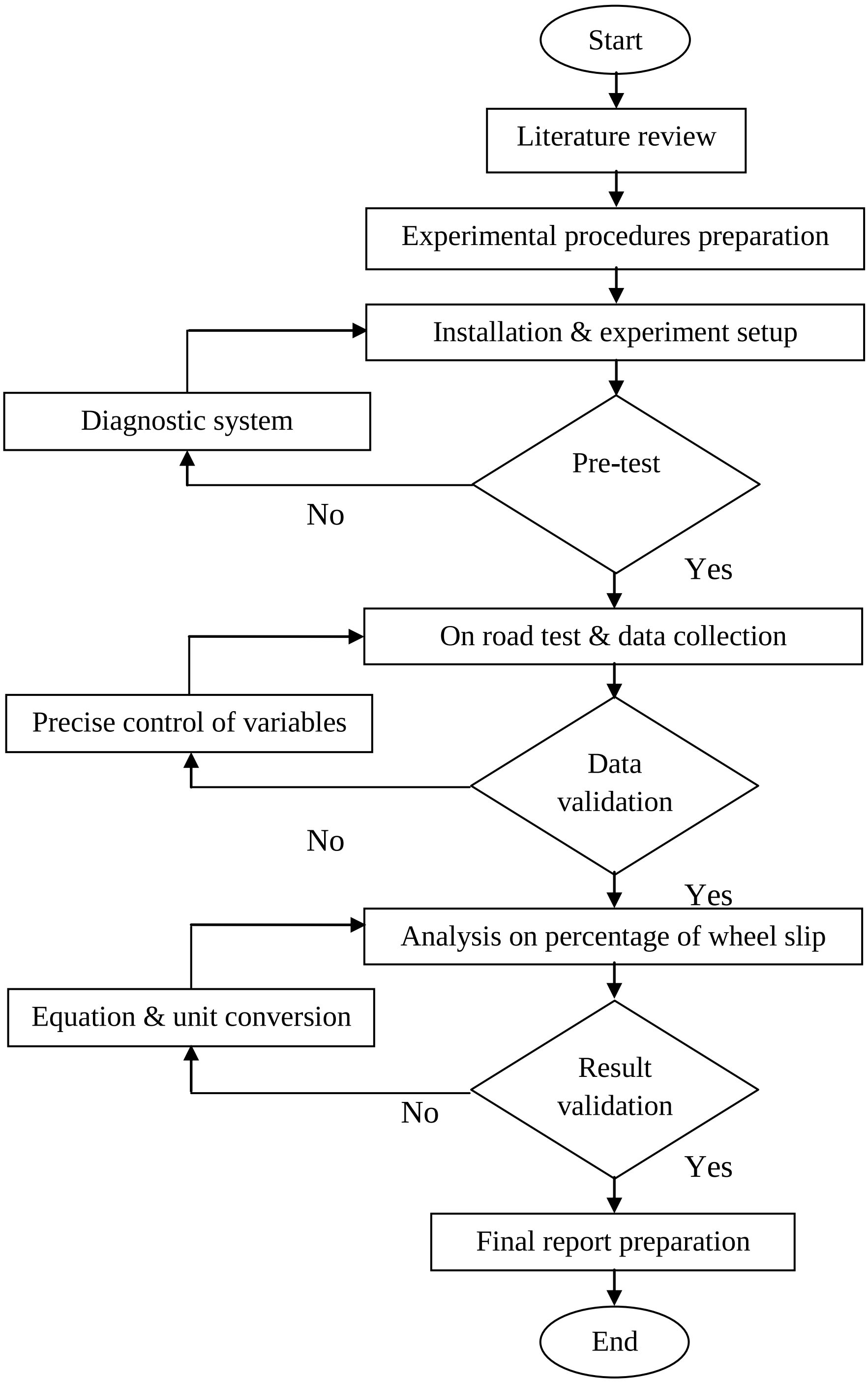


Figure 1.1: Flow chart of the project

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

While tire parameters are quite important to current vehicle systems and proposed future systems, these parameters are subject to considerable variability and are difficult to estimate while driving the unavailability of the absolute velocity (Miller et al., 2001). The study of the tire and vehicle characteristics is important before any measurement and testing is conducted to get the final result and conclusion.

The study for the tire and road interaction is covering most on the tire road friction, tractive and braking effort of the tire and the braking properties on wet roads. This chapter will cover on the longitudinal force and slip which will study both for driving and braking maneuver. This chapter concluded with the application of the slip parameters in the Antilock Braking System (ABS) for vehicle stability control.

2.2 TRACTIVE PROPERTIES OF TIRES

2.2.1 Tire-Road Friction

Tire are specifically designed to grip the road surface when the vehicle is being steered, accelerated, braked and/or negotiating a corner and so to control the tire to ground interaction is of fundamental importance (Heisler, 2002). Road grip or friction is the resistance to relative tangential motion during braking or driving at the compressive contact interface between a tire and the road surface (Brach, 2006).

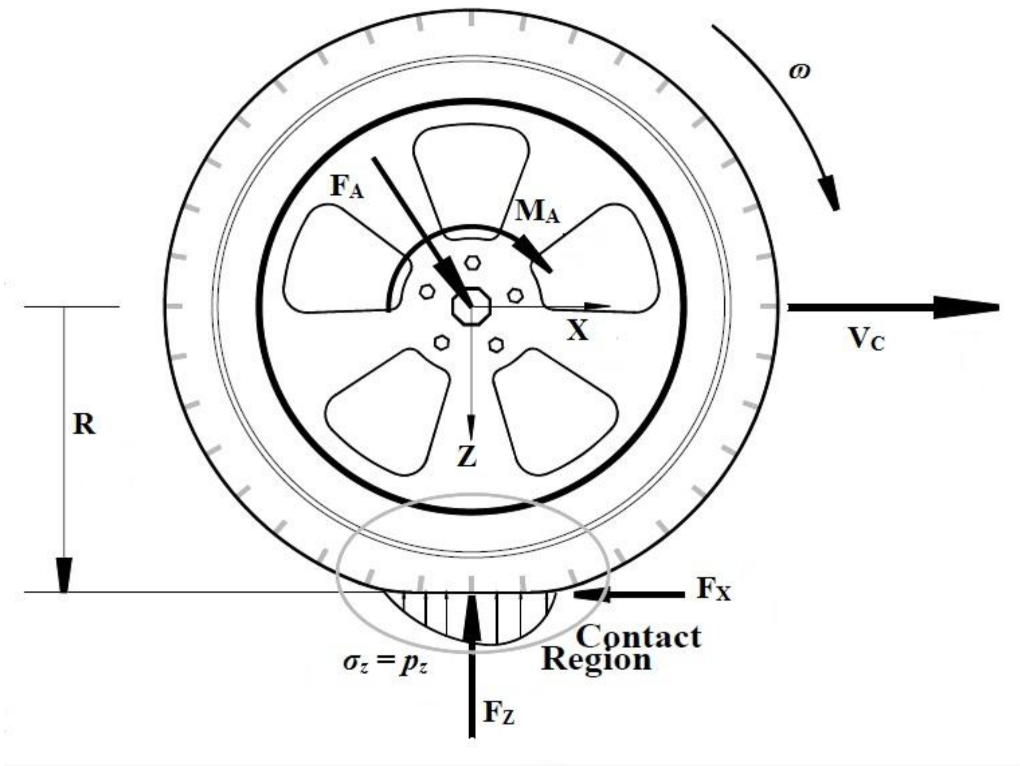


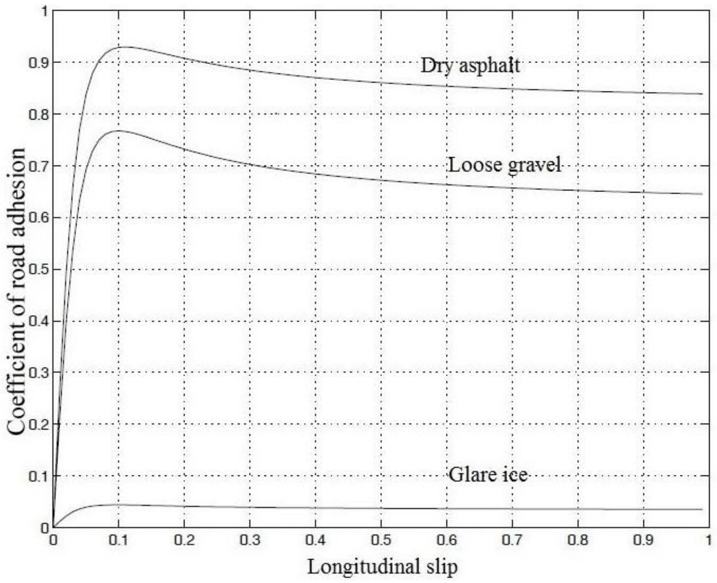
Figure 2.1: Free body diagram of rotating wheel

Source: Brach (2006)

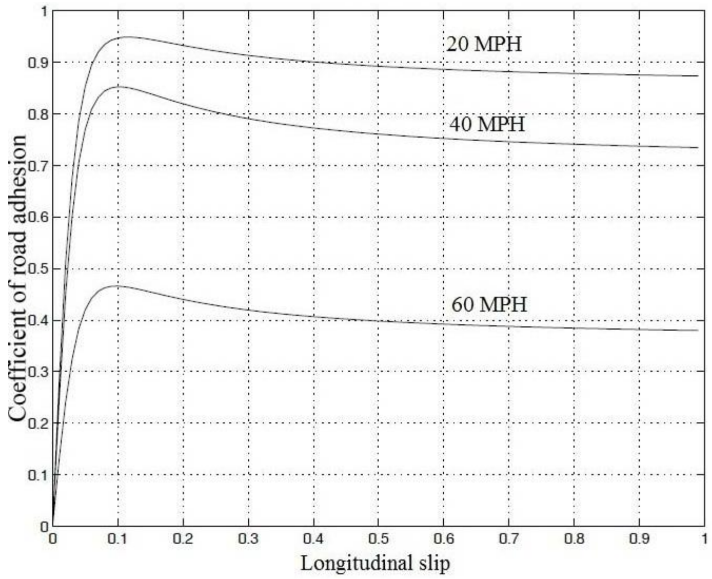
Figure 2.1 show a rotating wheel of a vehicle. R, F_A and M_A is the force system applied to the wheel, F_Z is the normal force between the tire and the road surface, F_X is the frictional force between the tire and the road surface.

The normalized traction force, μ, is defined as:

$$\mu = \frac{\sqrt{Fx^2 + Fz^2}}{Fz} \tag{2.1}$$



(a)



(b)

Figure 2.2: Tire - road friction for different (a) road surfaces and (b) vehicle velocities

Source: Harned et al. (1969)

In longitudinal motion, the lateral force F_Y can be neglected. The above equation then becomes:

$$\mu = \frac{Fx}{Fz} \tag{2.2}$$

The ratio of tangential force, *Fx*, to the normal force, *Fz*, is defined as the coefficient of friction, μ. This normalized tire friction, μ, is a nonlinear function of the normalized velocity between the road and the tire with a distinct maximum (Canudas-de-Wit and Tsiotras, 1999). The variation of friction coefficient is depending on the velocity of the vehicle and road surface condition, among other factors as shown in Figure 2.2 below (Harned et al., 1969).

2.2.2 Tractive and Braking Effort

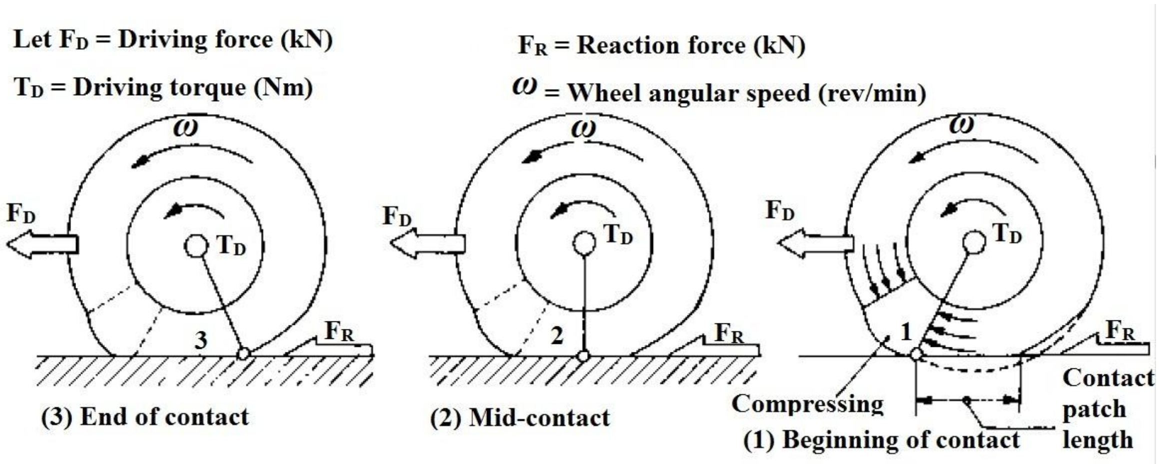


Figure 2.3: Deformation of tire under driving torque

Source: Heisler (2002)

Tractive effort of a tire to the ground is produced when a driving torque is transmitted to the wheel and tire. The twisting of the tire carcass in the direction of the leading edge of the tread contact patch is continuously opposed by the tire contact patch reaction on the ground. A portion of the tread and casing will be deformed and compressed before it enters the contact patch region (Wong, 1978). Hence, the distance that the tire treads travels when subjected to a driving torque will be less than that in free rolling as shown in Figure 2.3 below.

When a braking torque is applied to the wheel and tire, the vehicle inertia will tend to pull the wheel forward while the interaction between the tire contact patch and ground will opposed this motion. Because of this action, the casing and the tread elements on the leading edge of the tire become stretched just before entering the contact patch region as shown in Figure 2.4. Braking torque will increase the distance travel by the tire and will be greater compare when the tire is subjected to free rolling (Heisler, 2002).

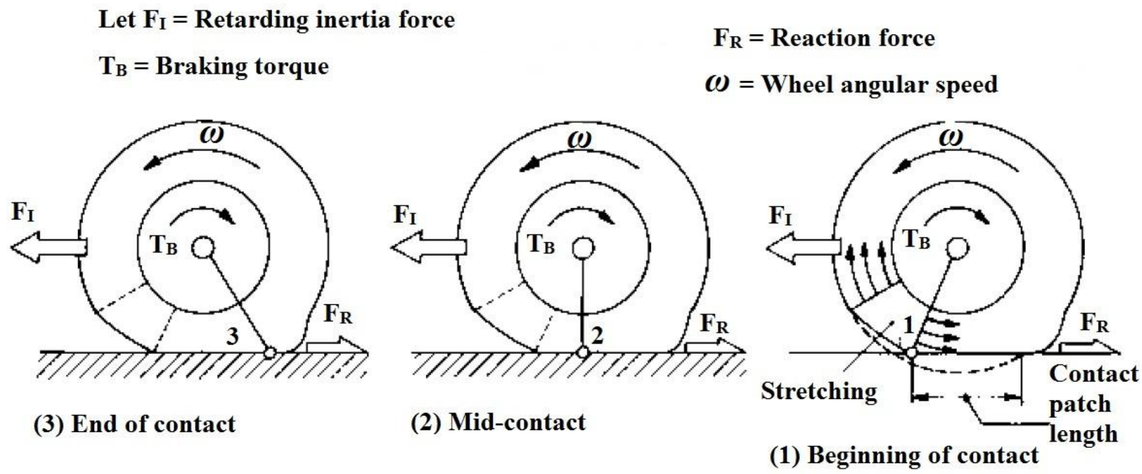


Figure 2.4: Deformation of tire under braking torque

Source: Heisler (2002)

The phenomenon of the gain or loss in the distance the tread travel under tractive or braking conditions relative to that the free rolling is known as longitudinal slip. Figure 2.5 shows the effect of driving torque to the tire slip. Tractive effort will increase slightly matched proportionally with the percent slip. The tread elements will eventually reach its distortion limit and parts of the tread elements will begin to slip until the limiting tractive effort is developed. Further increase in the percentage of slip will cause the vehicle under unstable condition because of that the decrease of the tractive effort until pure wheel spin is developed (Heisler, 2002).